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Early Pleistocene River-Fed Paleocoast in Western Umbria (Central Italy): Facies Analysis and Coastal Models

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Abstract: Pliocene (?)—early Pleistocene shallow marine deposits, varying from gravel to sand to clay, characterize the southernmost sector of the Valdichiana Basin, between Orte and Città della Pieve, across Tuscany, Umbria and Latium (Central Italy). Facies associations, referring to the evolution of a river-fed coast, with a sensible facies heteropy, and a sub-environment articulation, both across and alongshore, have been recently described. Although the main part of the territory responds to a wave-dominated coastal model, a clear fluvial sediment origin and the presence of localized river mouths have also been documented. Nearshore is mainly represented by interbedded sand and gravel beachface to upper shoreface deposits, in which both a mouth bar organization and a lateral distribution of gravel beaches are recognizable. Sediment origins largely depend on debris flow processes, related to small alluvial fans/fan deltas. In constrained areas, debris flow and current continental deposits occur, referring to coalescent alluvial fans, organized as a smoothly seaward-dipping piedmont band, drained by shallow braided channels. This roughly organized fluvial system feeds a coastal area, with a fandeltabuild-up. The as-described fan delta and beach systems are characterized by a smooth seaward morphology, according to models resembling, on a coast-transverse profile, the shelf-type fan delta. Although the proposed models differ from each other's, with respect tothe shelf-type one, this is mainly on a lateral facies distribution.

Keywords: facies analysis; coastal environment; shelf-type fan delta; early Pleistocene; western Umbria

1. Introduction

The coastal marine environment represents a very complex context of sedimentation, both today and in the past, due to interactions between continental and marine processes. On ancient deposits, distinctions among deltaic and non-deltaic, river-, tide- or wave-dominated coasts have been commonly used, and a large amount of literature exists, particularly for river- and wave/storm-dominated coast sedimentation models [1–15]. In present day coasts, fluvial currents, waves and tides act together, and the role of each group of processes is often hard to discriminate; nevertheless, the aforementioned distinction permits interpretation of facies associations in terms of sedimentation models. Interaction among eustacy, tectonic subsidence and sedimentation rate determinate a high complexity in coastal depositional architecture, but also allows the analysis of deposits in terms of relative sea-level changes. Coastal and nearshore deposits are often incompletely preserved; nevertheless, they record relative sea-level changes as shift of facies associations landward or seaward, respectively [1,6,7,11,16]. Coastal systems evolution is conditioned by relative sea-level fluctuations, and often records short- and long-term cyclicity as transgressive and regressive cyclic deposits [17–22].

The study area is characterized by the occurrence of shallow water, wave-dominated deltaic deposits in the northern sector [23,24], rocky coast deposits southwards [24–26], and by small river- to alluvial fan-fed coasts, covering a wide part of the basin and laterally shading to reworked gravel to sandy beach systems [24,26]. The fluvial origin is often recognizable, although facies associations vary across- and alongshore [27].

The study area, as well as the paleoenvironments each time proposed to characterize it, have been classically associated with the post-Messinian evolution of the Tyrrhenian paleocoast, progressively migrating from the Apennine chain towards the present-day position [24,28–36].

This work is placed into a series of former contributions [23–27], mainly devoted to the paleontological and stratigraphic features, and it is aimed to complete the sedimentological reconstruction proposed for the study area. In detail, this research focused on the interpretation of facies variations occurring in these small river- to alluvial fan-fed coastal marine deposits, with the aim of proposing depositional architecture models. Environmental and stratigraphic comparisons with deltaicand rocky coast systems, formerly described in the study area [23,25], are also proposed.

2. Geological Setting and Stratigraphic Constrains

The present day Valdichiana valley, at the Umbria–Tuscany–Latium boundary in central Italy, is a NW–SE oriented extensional basin (South Valdichiana Basin [24,28,29]) bounded to the east by the Mt. Pegliarange, the Paciano–Panicalelineage and the present-day Trasimeno Lake, and to the west by the Rapolano–Cetona range (Figure 1).

On both the eastern and western reliefs, a Triassic–Miocene rocky substratum crops out [30–34,37,38]. On western reliefs, Tuscan and Ligurids Lithostratigraphic units crop out, whereas on the eastern ones the northern sector is mainly ascribable to the Tuscan units, and the southern part (Narnese–Amerina ridge) to Umbria–Marche carbonatic units (Figure 1).
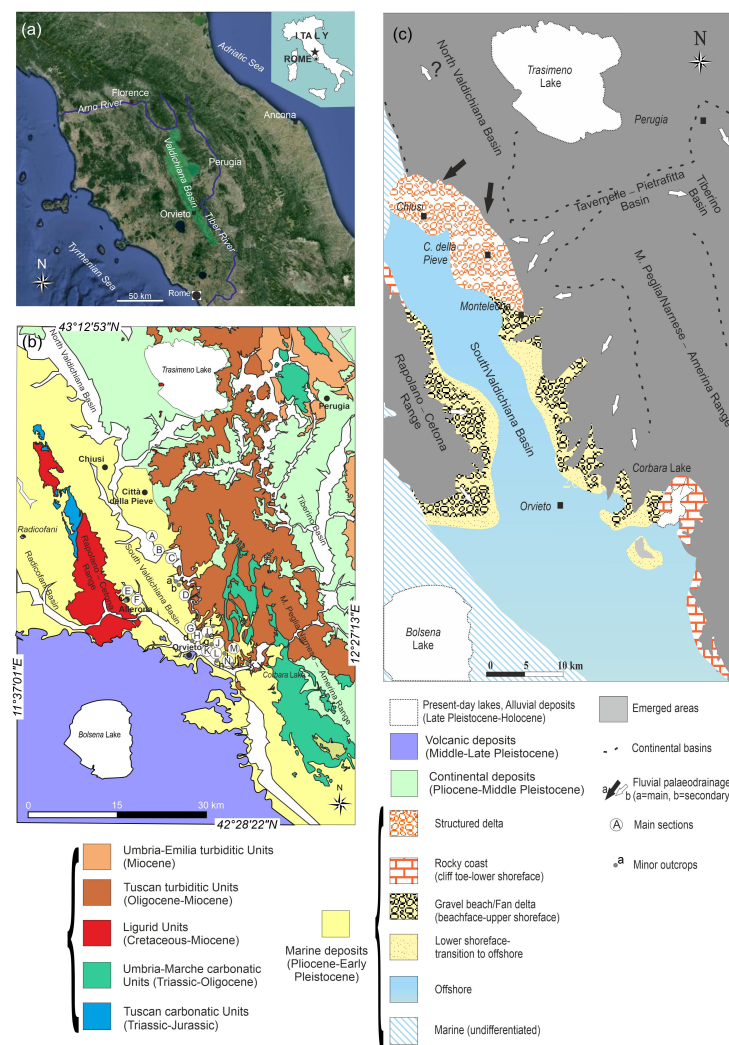

Figure 1. (**a**) Ubication, (**b**) geological sketch and (**c**) paleodepositional restoration for the study area (redrawn and modified after [24,27,39]).

Marine to continental deposits, with volcanoclastic episodes, filledup the basin from the Pliocene to late Pleistocene/Holocene [24].

Specifically, the South Valdichiana Basin presumably underwent continental conditions during the Late Miocene [34], and developed as a marine environment from the Early (?) Pliocene to Late Pliocene [30,37,40] ("Cycle I" in Figure 2 [24]). This older cycle, widely cropping out in the neighbouring basins [24,29,41], is poorly documented in the study area [24], and the high environmental variability of continental, coastal marine and distal marine environments was mainly referred to as the Early Pleistocene "Valdichiana Cycle" (Figure 2, [24]). This cycle was dated to the Gelasian–Calabrian interval [24], by means of calcareous nannofossils (CNPL4 pro parte—CNPL9 pro parte zones [42]) and planktonic foraminifers (*Globorotalia inflata* p.p.-*Globigerina cariacoensis* p.p. zones [43]). In this time interval, deposits record a wide facies heteropy [23–26], both along and across the paleoshoreline.
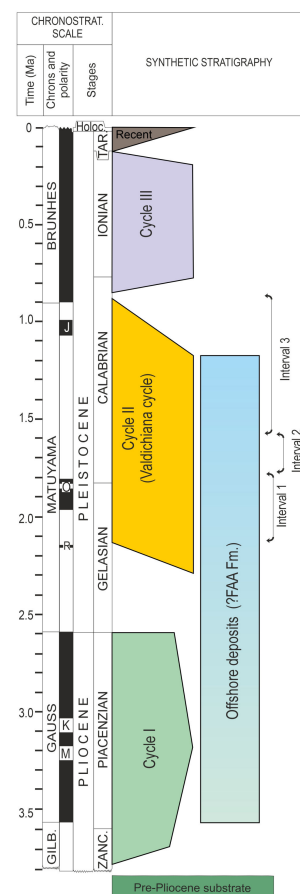

Figure 2. Stratigraphic scheme (modified after [24,27,39]).

The youngest sedimentary cycle, before the onset of the present-day environmental setting, was indicated as Cycle III [24] and dated to Middle–Late Pleistocene. It was characterized by the onset of lacustrine conditions (Paleo–Trasimeno) northwards [44,45], and, in the southern sector, by several volcanic and sedimentary units related to the Vulsini, Vico, and Sabatini Mts. volcanic activity [24]. Nonetheless, older Vulsini Mts. volcanic deposits were documented in both marine and continental deposits of the Valdichiana Cycle (Figure 2, [24,46]).

3. Materials and Methods

A total of 27 sedimentary sections and minor outcrops, described through several research campaigns [24] have been revized here, in terms of sedimentary features. Se-

lected sedimentological and stratigraphic sections have been redrawn, to put emphasis on facies associations.

In sedimentological description, classical grain size scales and parameters, as well as morphometric and textural nomenclature, were adopted [47–53]. Codes for sedimentary structures refer to commonly used manuals [54–56].

Stratigraphic schemes refer to the one recently proposed for South Valdichiana [24], and the biostratigraphic scales of [42,43], for Planktonic Foraminifers and Nannofossils respectively, have been adopted. The chronostratigraphic scale refers to [57].

4. Results

4.1. Textural Features

While still slightly variable from one outcrop to one another, deposits show recurrent features on lithology and petrological composition, grain size, and sedimentological parameters. The present research was focused on field facies description and interpretation. Original statistical data were partly included in a former work ([27], with references therein).

4.1.1. Coarse-Grained Deposits

Clast- to matrix-supported gravel and conglomerate represent the coarser fraction for study deposits, with diameters for clasts varying between 4 mm (-2φ, fine pebbles) up to 0.5 m (small boulders). The mean particle size falls between 6 and 25 cm ($-6\varphi/-8\varphi$, vcP to cC). Morphometric features are variable; clasts vary from subangular to rounded, although the commonest shapes are "plate" or "equidimensional". Gravel/conglomerate bodies are usually poorly- to moderately- well sorted. Clast lithology varies from site to site, although limestones from both Tuscan and Umbria–Marche stratigraphic units and sandstones with prevailing Tuscan affinity prevail.

The sandy fraction varies from fS to vcS/G (5φ to -1φ). Grains are prevailing made of quartz or lithic fragments, usually angular to subangular, or plate laminae of micas, accompanied by a variable fossil component (microfossils or shell fragments), still in the range of sand. Sandy deposits are commonly moderately-well-sorted to well-sorted.

4.1.2. Fine-Grained Deposits

The finer deposits range from 125 μm (5φ, vfS) to less than 4 μm (clay); usually, grains with diameter < 63 μm (4φ) reach percentages of 80–98% [27], where the clay fraction ranges between 20 and 50% [58]. Except for the sandy fraction, which shows the same features described above, silty to clayey fractions are commonly recognizable only through laboratory analyses; thus, deposits can be only described in outcrop as generic clayey silt to silty clay. Where analyzed [58] (Table S1, with references), mineralogical/petrological parameters showed a substantial homogeneity; clay minerals (between 55 and 69 wt.%) prevail, with minor (<15 wt.%) quartz, feldspars, and calcite, and a local occurrence of dolomite (2 wt.%). Among clay minerals, a prevalence of kaolinite (16–27 wt.%), a significant presence of chlorite and illite (both between 15 and 19 wt.%), and a minor presence of mixed phases were reported [58].

4.2. Facies Analysis and Fossil Assemblages

Seven main facies associations and their related facies have been described, associated with environments varying from proximal alluvial/coastal to distal marine conditions. Considering each association, single facies may or may not be found together in outcrop.

4.2.1. Facies Association A—Alluvial Fan

The facies association A groups facies referred to a slight-to-moderate organized alluvial environment.

- Facies A_1—Irregular alternations of lenticular-shaped clast–supported gravel beds and parallel cross-laminated coarse sand layers (Figure 3a). Gravels are mainly made

of plate, well-rounded, limestone medium to coarse pebbles, showing a(t)b(i) current imbrications (sensu [56]). Interpretation: sheetflood deposits.

- Facies A_2—Slightly organized, very coarse-grained matrix–supported gravel beds (Figure 3a). Gravels, varying from fC to mC, are made of well-rounded limestones, locally showing a(p)a(i) gravity-flow imbrications (sensu [56]). Interpretation: channelled non-cohesive debris flow deposits (sensu [10]).
- Facies A_3—Channelled clast–supported, Gp cross-stratified gravel, with minor Sp cross-laminated sand layers (Figure 3a). Interpretation: longitudinal gravel to sandy bar deposits (sensu [59]).
- Facies A_4—Unorganized matrix-supported gravel beds, with low lateral extension (Figure 3b,d). Grain size of gravel is extremely variable, from fP to small boulders (from $\phi = 1$ cm to $\phi > 50$ cm), whereas the matrix is comprized between vcS and Granules. Interpretation: unchannelled non-cohesive debris flow deposits.

Figure 3. Alluvial fan and fan-delta front facies associations: (**a**) alternance of facies A_2 and A_3, with minor facies A_1 (Il Caio outcrop, N in Figure 1); (**b**,**d**) unorganized gravel of (facies A_4) from Ficulle (**b**) and Bagni (**d**) outcrops (a and G in Figure 1, respectively). Occurrence of beachface facies C_2 (see below) is also reported; (**c**) channelled gravel of facies B_2 (Corbara outcrop, k in Figure 1); (**e**) progradation of facies B_3 (the sense of movement is perpendicular to the page) over facies B_4 (Corbara outcrop); (**f**,**g**) particular of facies B_3 and B_4, respectively.

Fossils are very uncommon inside deposits of facies association A, mainly represented by vegetal remains and mollusc fragments. A rare assemblage of freshwater molluscs (*Theodoxus groyanus*, *Melanopsis affinis*, *Unio* cf. *U. pillai*, *Planorbis* sp.) was locally reported, associated with facies A_3 [46,60].

4.2.2. Facies Association B—Fan-Delta Front

- Facies B_1—Parallel-laminated to massive fine-grainedsediments (vfS to mud), with mixed brackish and marine micro- and macrofaunas, vegetal fragments, and/or sandy (vcS) bioclastic horizons and large mollusc (mainly oysters) layers.Micropaleontological assemblages with species tolerating altered salinity conditions are locally documented [60]. Interpretation: brackish coastal ponds/lagoons isolated between distributary channels or by submarine bars.
- Facies B_2—Channelled mixed gravel and sand, cross-stratified deposits, interbedded with barren to poorly fossiliferous sandy to silty layers (Figure 3c). Channel axial directions are dispersed from SW to SE. At the base of the channels a vcP (ϕ = 5–6 cm) channel lag occurs, with poorly reworked marine macrofossils (mainly *Ostrea lamellosa*, *Persististrombus coronatus*, *Conus* sp., *Thericium* sp.) and shell debris. Interpretation: distributary channel deposits.
- Facies B_3—Lenticular-shaped, clast-supported gravel beds, intermingled with sand (Figure 3e,f). Gravel beds are up to 1–1.5 m thick (in the middle part), but thickness shade laterally to a single clast. Additionally,texture tends to be progressively matrix-supported, to finally shade into sand. Through the same trend, the diameter of gravel varies from ϕ > 25 cm (fine boulders) to ϕ = 4–6 cm (vcP), with an MPS (Mean Particle Size) of ~10 cm. Clasts are mainly blade- to disc-shaped, rounded to well-rounded limestones, although sandstone lithotypes also occur. Finer sediments are fS/mS, moderately well-sorted, angular, high sphericity calcarenites and micas laminae, with minor cherty grains. Interpretation: organized mouth bar deposits.
- Facies B_4—Well-sorted, biotubated fine to medium sand (fS/mS), with angular high sphericity grains. Bioclastic lags, produced by waves and partly reworked by organisms, also occur (Figure 3e,g). Interpretation: Interdistributary bays, sheltered bay/lagoon deposits.

4.2.3. Facies Association C—Beachface

- Facies C_1—Poorly organized, wedge-shaped erosional-based gravel beds, laterally (from east to west) reducing to one-clast thickness and then shading to sand (Figure 4a,b). Texture ᵢs mainly clast-supported, but locally can vary to matrix-supported or open-work as well. Deposition close to the shoreline is testified by the occurrence of both *Lithophaga* boring and encrusting species (as barnacles or oysters).
- Clast average diameter is ~10–15 cm (fC/cC), with larger fragments up to 40–50 cm (Boulders), and smaller pebbles (ϕ~3–4 cm). Rounding varies from subangular clasts to rounded/well-rounded gravel, whereas the sandstone and limestone lithologies prevail. Interpretation: beachface slightlyreworked delta front deposits.
- Facies C_2—Medium-to-coarse-grained sand (mS/vcS), well-sorted, with angular to subangular high-sphericity grains (Figure 4a,c). Sands are mainly lithoarenites, with locally subordinated quartz and micas fragments. Beds are locally massive, but commonly two superimposed orders of structures are visible: lowermost symmetrical dunes, with shore-dipping Sp cross-laminations, and uppermost symmetrical ripples, with pointed crests. Interpretation: Mixed-sand and gravel submarine dunes, longshore bar deposits.

Figure 4. Beachface to shoreface facies associations: (**a**–**c**) interfingered C_1 and C_2 facies (La Croce outcrop, (b in Figure 1); (**d**) facies D_2 and D_3, with minor facies E_1 at the base (Osarella I outcrop, K in Figure 1).

4.2.4. Facies Association D—Shoreface

- Facies D_1—Medium-to-fine sand (mS/fS), with subordinated gravel layers, showing different features:
  - Lenticular-shaped, up to 10 cm-thick layers of granules to fine pebble clasts (G/fP).
  - Mound-shaped layers of granules, up to 10 cm-thick, with local cross-lamination.
  - Lenticular, erosional layers, normally graded (from fP to G), with bioclasts and large mollusc disarticulated valves (mainly oysters).

  Interpretation: Mixed-sand and gravel submarine dunes, longshore bar deposits.

- Facies D_2—Mixed-sand and gravel layers (Figure 4d), ~30–40 cm-thick, with multiple undulate scour surfaces, with λ~1.5–2 m and h~10–15 cm. Grain size varies from vcS/G to cP/vcP (0.2 cm < ϕ < 4 cm). Deeper scours are filled by a pebble lag

followed by Sp cross-laminated sand, mainly dipping coastward. Minor concave-upwards surfaces, marked by cP, alternating to undulate-laminated fS layers, also occur. Interpretation: Storm deposits.

- Facies D_3—Fine sand (fS) layers showing parallel-, undulate-, to slight cross-laminations. Sets of laminae are often separated by thin litho- or bioclastic lags, in the size of medium sand (mS). Locally, symmetrical ripples are also recognizable. Interpretation: fair-weather deposits.

4.2.5. Facies Association E—Distal Marine Deposits

- Facies E_1—Medium-to-very-fine sandy deposits (vfS/mS, Figure 5a), often massive, locally showing undulate to slight cross-lamination. Fossil layers, commonly with erosional base surface, widely occur (Figure 5b). They can be alternatively represented by bioclastic lags and isoriented valve olygotipic bivalve horizons (*Glicymeris* sp., pectinids and oysters). Graded lithoclastic lags also occur. Deposits are commonly bioturbated: among trace fossils, *Thalassinoides* isp. Prevail. Interpretation: moderate-energy storm deposits in the oscillatory wave zone/shoaling wave zone, lower Shoreface deposits.
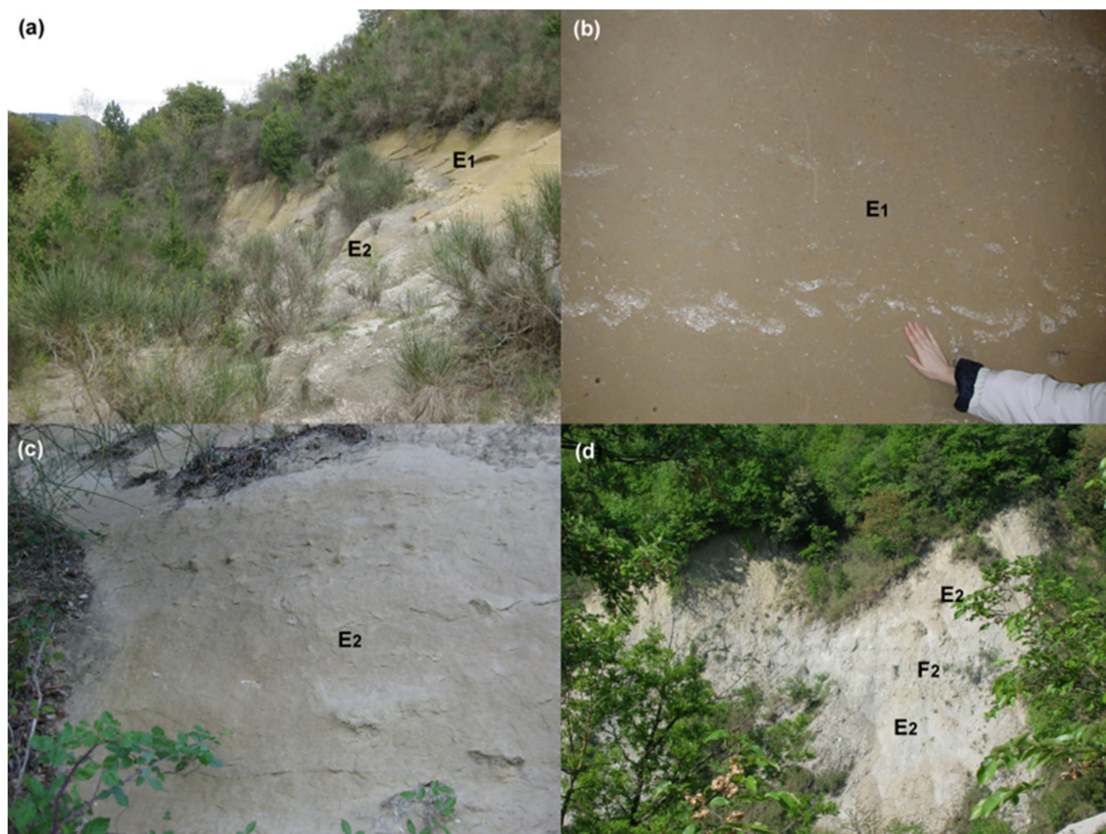

Figure 5. Distal marine facies associations: (**a**,**c**) lower shoreface (E_1) to offshore transition (E_2) facies ((**a**) S. Lazzaro quarry, (**c**) Osarella II outcrops, C and J in Figure 1, respectively); (**b**) facies E_1—bioturbated storm deposits (La Casella outcrop, H in Figure 1); (**d**) resedimented gravel into clayey deposits (facies F_2, La Sala outcrop, D in Figure 1).

- Facies E_2—Structureless to parallel- or undulate-laminated silty sand (vfS/S). Where visible, laminae are organized in decimetres-thick sets. Litho- and bioclastic lags (distal tempestites), partly bioturbated, commonly occur, together with sparse fossils (often in life position) and *Thalassinoides*-like fossil traces (Figure 5c). Whole, unbroken molluscs often concentrated in layers (c-case sensu [61]; low-sedimentation rate, related to Transgressive System Tract (TST) or Maximum Flooding Surface, sensu [62]).

It is not excluded that broken/unbroken mollusc layers may represent evidence of repeated storm/fairweather cycles, although they are not always strictly correlated. Interpretₜation: transition to offshore deposits.

4.2.6. Facies Association F—Prodelta

- Facies F1—Grey-to-light blue, parallel laminated silty clays, which document both a rich marine micro- and macrofauna and vegetal remains. Interpretation: Prodelta deposits.
- Facies F2—Clay/silty clay deposits with gravel (fP to CP) layers. Interpretation: storm- or seismic-induced debris flow deposits, fan-delta bottomset resedimentation.

4.2.7. Facies Association G—Offshore

The distal deposits are represented by massively- to thinly-laminated gray–blue silty clay, cropping out in a narrow band in the central part of the basin. Throughout the whole area, deposits show no significant sedimentological differences. Main structures are represented by horizontal laminations and fossil layers, although fossils are also sparse in the sediment. The percentage of fines $\phi < 63$ μm (4φ), i.e., the upper limit for settlement [63], is commonly more than 80%, indicating a settlement-dominated environment. Nonetheless, variable percentages of coarse grains also occur. The fossil assemblages (mainly benthic and planktonic foraminifers) suggest a relatively deep offshore environment (up to 80–130 m [24,27,39]), below the storm wave-base; still close enough to the shoreline to reflect the coastal processes.

5. Discussion

5.1. Arrangement of the Mountain Reliefs and Inherited Coastal Morphology

A first aspect to consider concerns the lithological nature and the arrangement of the reliefs, which constitute the substrate on which the Pliocene and Pleistocene deposits rest. Sandstones lithotypes dominate, in layers from 20–30 cm up to one metre-thick, alternating with decimetre-thick intercalations of thinly-laminated clays. Carbonate lithotypes, otherwise, mainly referring to Scaglia Toscana and Maiolica Lithostratigraphic units, mainly crop out in the deep incisions made by the watercourses, while the Jurassic and Cretaceous formations of the Umbria–Marche Succession are almost never cropping out along the western slope of the Mt. Peglia ridge.

At the expense of the "turbiditic" sandstones (Macigno s.l Fm) and, to a lesser extent, of the limestones (e.g., Scaglia Toscana Fm), erosion currently produces an eluvial blanket made up of heterometric clasts, immersed in an abundant silty-to-clayey matrix. The present-day hydrographical network on the slopes consists of a number of small but deep-incized streams. Now as well in the past, these features exposed the slopes both to landslides, mainly during parossistic rainfall events, and to a general remobilisation of sediments by debris flow and sheetflood processes. On the other hand, the watercourses, with a torrential regime, which can occasionally receive and sort the material coming from the slopes downstream through channelled processes, are both associated with traction currents and massflow.

Regardless of the relative altitudes or the recent tectonics, the mountain ridges bounding the basin should have not been very different from present-day when they were the shores of the Paleo–Tyrrhenian Sea, during the early Pleistocene.

Two aspects require a reflection: first of all, the mountain range, before the marine transgression of the lower Pliocene, must have known a moment of exposure and sub-aerial modeling, with subsequently inherited morphologies and marked lateral facies variability along and across the paleocoast.

Secondly, the processes modeling the slopes were strongly conditioned both by the climatic conditions and by the lithological and structural features of the rocky substrate.

In the case study, these characteristics determined low coasts and were strongly influenced by fluvial–alluvial processes, while the formation of high coasts, with cliffs, was much more difficult to develop.

The processes typical of the coastal marine environment, mainly the wave motion, re-worked deposits, conditioning their final morphology and determining a sub-environmental zoning both along- and across-shore.

5.2. Facies Architecture and Coastal Models

The described facies associations crop out in a wide area on both sides of the basin (Figure 1), and they highlight paleodepositional variability both across- and alongshore. Some sedimentological sections have been chosen, to highlight the vertical organization and the lateral (stratigraphic) relations (Figure 6).
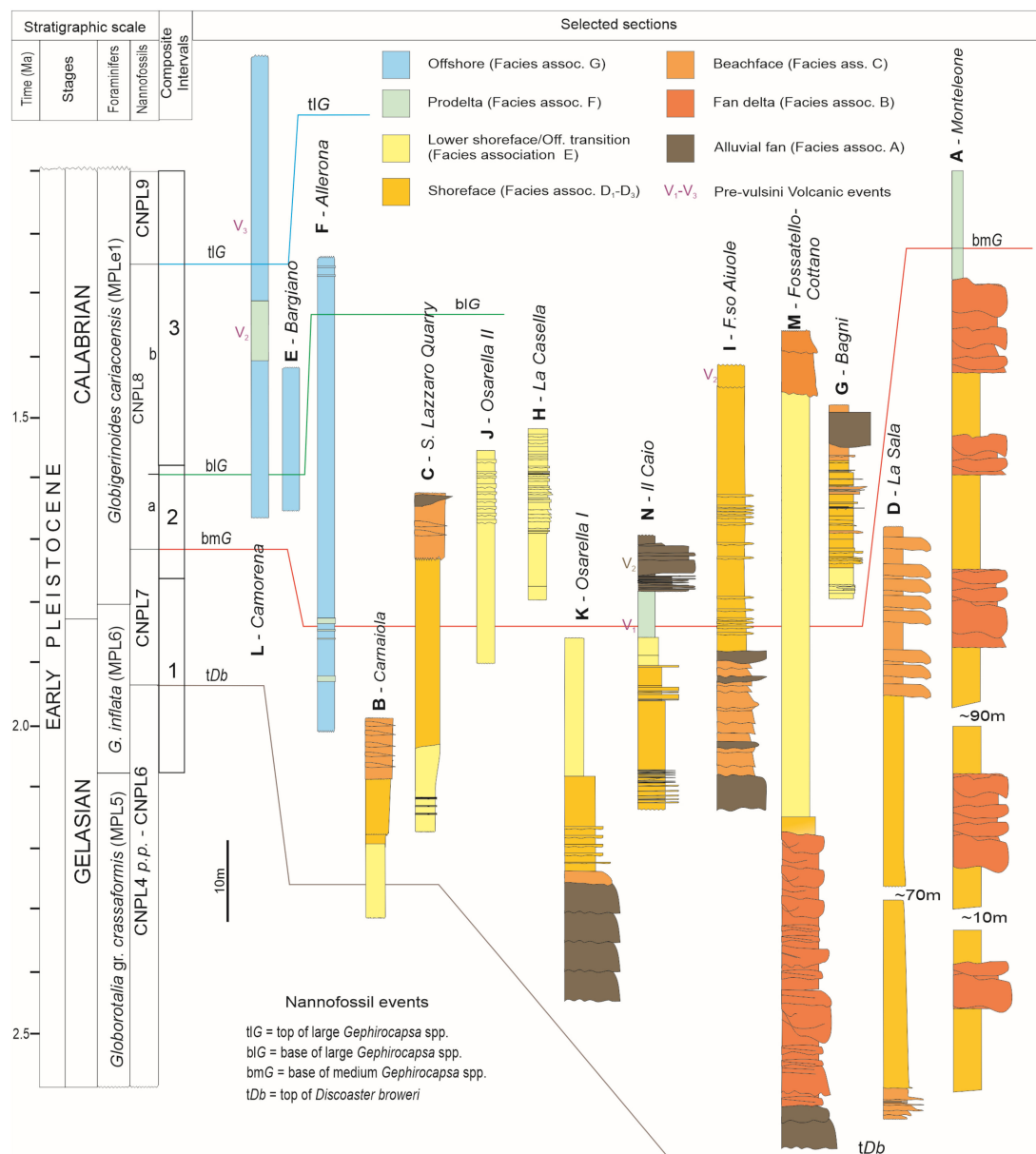

Figure 6. Selected sedimentological/stratigraphic sections. Letters indicating sections are the same as in Figure 1.

The area responds to a wave-influenced coastal model, especially during storm events which, at least in some moments, seem to have had a short period of recurrence.

The deposits recognized within the various sub-environments have a fluvial to alluvial origin, which in many cases is still recognizable despite the action of the waves. The described facies associations allow us to propose two different sedimentary models, which can be considered as end-members in the coastal variability in the area, and which have been defined as fandelta-dominated and gravel beach-dominated coasts, respectively. In both cases, the proximal part is characterized by a smooth seaward morphology (Figure 7), and reflects acrossshore the organization of the shelf-type fan delta model [8,13,14,64]. Due to this gently seaward-dipping morphology, minimal variations on the sea level caused a large shift of facies both shore- and seawards. Such variations were documented in study outcrops (Figure 6).
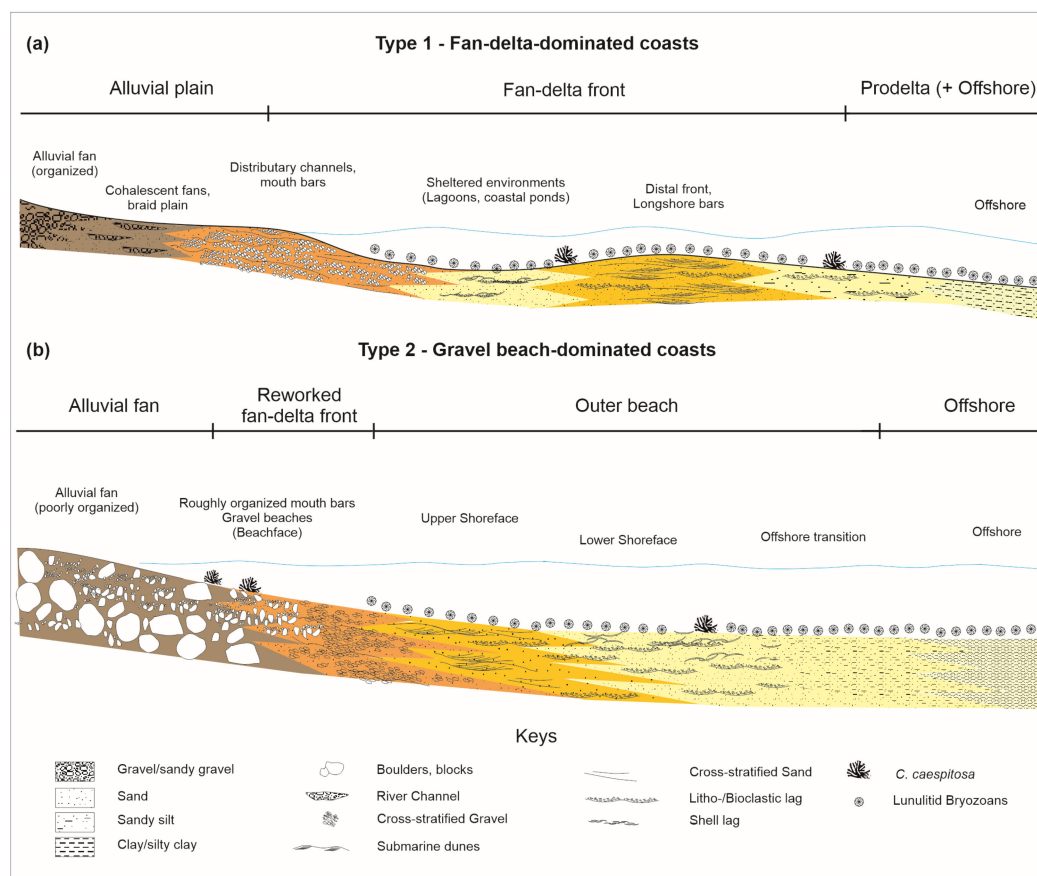

Figure 7. Coastal models. (**a**) Fandelta-dominated palaeocoast (Type 1); (**b**) Gravel beach-dominated palaeocoast (Type 1). The distributions of *Cladocora caespitosa* and lunulitid bryozoans refers to [26,27], respectively.

Nonetheless, the proposed models differ from each other's, with respect to theshelf-type one, mainly on lateral facies distribution, and some distinction between environments, associated with the two coastal models, can be proposed.

If in the proximal (nearshore) deposits the influence of both river/alluvial processes and wave action is still recognizable (although the prevailing ones are not always easily recognizable), differences within deposits become less marked across-shore. In particular, distal marine deposits, from lower shoreface to offshore, show laterally continuous homogeneous features.

5.2.1. Fan Delta-Dominated Coasts (Type 1 Model)

- Organized alluvial fan—The subaerial part of this coast consists of both fluid flow and sediment gravity flow deposits (facies A_1 to A_3; Table 1), all referable to slight organized alluvial fan (Figures 7 and 8). This environment was firstly associated

with single alluvial fan [46,60], reworking locally volcanoclastic deposits, although it probably better matches with a gravel-dominated, shallow-channel braided fluvial model (e.g., "Type 1", "Scott type" models sensu [55]). In fact, this environment and its facies associations could be better considered as part of a stepped and laterally extended braided system, probably on the top of coalescent fans (Bajada [65,66]). In such an environment, local situations could also be interpreted as lahar deposits (Morgavi D., pers. comm. 2018). In any case, both massive and current processes have been documented. Interpretation: Large or coalescentalluvial fan, bajada.

- Fan delta front—B_3 (organized mouth bar deposits) and secondarily B_2 (distributary channel deposits) facies prevail: gravel bodies, and subordinate sand, show a clear fluvial origin and transport, and were sedimented and partly reworkedin a shallow (10 to 20 m) coastal environment. Deposits were probably related to intermittent discharge; gravel shade to marine sand both laterally and frontally, with a prevailing progradation seaward which can be related to short frequency sea-level variations or to sedimentary supply as well. Facies B_1 was less commonly documented. Small brackish ponds could locally have formed between the channels. Mouth bars, although reworked by waves, were localized, and higher lateral facies continuity was probably reached only in correspondence of the external bars, quite far from the coast at the passage to the prodelta. Here, waves probably built submarine longshore bars (facies D_2) and isolated sheltered environments as lagoons or interdistributary bays (facies B_1).

- Prodelta—It was mainly represented by facies F_1, although a clear distinction from off-shore deposits (facies G) is not easy in outcrop, and often related to macro/microfossil assemblages and laboratory analyses [27,67]. The transition to the prodelta was probably gradual, through a gently inclined coastal morphology and with a progressive increase in fine-grained fraction. Consequently, resedimented bottomset deposits (facies F_2, Figure 5d: see below), while still possible, are less commonly documented and mainly associated with the Type 2 coastal model.

Environments	River-fed paleocoasts			Rocky coasts
	Braid-river delta	Fan-delta dominated coasts (this work)	Beach dominated coasts (this work)	
Continental	Braid-river channels Alluvial plain	Large and/or coalescent alluvial fans	Small isolated alluvial fans	Cliff Cliff thalus
Transitional	Brackish	(Small ponds)		Cliff Cliff thalus
Marine (proximal)	Inner delta front { Distributary channels / Mouth bars / Interdistributary bays	Fan-delta front { Distributary channels / Mouth bars / Low energy environments (Lagoons, Interdistr. bays) / Mixed sand and gravel longshore bars	Beachface { Gravel beaches / Wave-reworked bars	Gravel beachface
Marine (proximal)	Large macroforms sandy outer delta front		Shoreface { Mixed sand and gravel longshore bars / Lower shoreface	Sandy/calcarenitic shoreface
Marine (distal)	Prodelta	Prodelta	Transition to offshore	
Marine (distal)	(Offshore)	Offshore	Offshore	Offshore
Present-day distribution	Northern sector South Trasimeno area (continental) Città della Pieve area (deltaic)	Localized, both valley sides (Monteleone, Fabro and Corbara areas)	Intermediate sector, both valley sides	Narnese-Amerina western flank

Figure 8. Comparison of coastal models for the study area.

Table 1. Facies associations (Figures 3–5).

Facies Association	Facies	Description	Fossils	Interpretation	Environment
A	A_1	Lenticular-shaped clast–supported gravel with a(t)b(i) current imbrications, irregularly alternated with Sp cross-laminated coarse sand	shell fragments vegetal remains	sheetflood deposits	Organized alluvial fan
	A_2	Slightly organized, very coarse grained matrix–supported gravel, locally showing a(p)a(i) gravity-flow imbrications	shell fragments vegetal remains	channelled non-cohesive debris flow deposits	
	A_3	Slightly organized, Gp cross-stratified clast- to matrix–supported gravel, local Sp lamination	freshwater molluscs vegetal remains	longitudinal gravel to sandy bar deposits	
	A_4	Unorganized matrix-supported gravel beds	shell fragments vegetal remains	unchannelled non-cohesive debris flow deposits	Unorganized alluvial fan
B	B_1	Parallel-laminated to massive fine-grained deposits (sandy clay to mud), sandy bioclastic horizons, large mollusc (mainly oysters) layers	vegetal remains mixed brackish and marine micro- and macrofauna	brackish coastal ponds/lagoons isolated between distributary channels or by submarine bars	Fan delta front
	B_2	Channelled mixed gravel and sand, cross-stratified, interbedded with barren to poorly fossiliferous sandy to silty layers	poorly reworked marine molluscs shell debris	distributary channel deposits	
	B_3	Lenticular-shaped, clast-supported gravel beds, intermingled with sand	Encrusters (oysters, barnacles, serpulids) *Lithofaga* borings	organized mouth bar deposits	
	B_4	Well-sorted, biotubated fine to medium sand, partially reworked bioclastic lags	shell fragments trace fossils	sheltered bay/lagoon deposits	
C	C_1	Poorly organized, wedge-shaped erosional based gravel beds, laterally shading to sand	Encrusters (oysters, barnacles, serpulids) *Lithofaga* borings	beachface slightly-reworked delta front deposits	Beachface
	C_2	Medium-to-coarse-grained sand, locally massive, with common symmetrical ripples, superimposed to Sp-laminated symmetrical dunes	marine molluscs shell debris	Mixed-sand and gravel submarine dunes, longshore bar deposits	
D	D_1	Medium to fine sand (mS/fS), with subordinated lenticular-shaped, mound-shaped or erosional/graded fine gravel layers	shell fragments vegetal remains large mollusc valves	Mixed-sand and gravel submarine dunes, longshore bar deposits	Shoreface
	D_2	Mixed-sand and gravel layers, with multiple undulate scour surfaces, with pebble lag and coastward-dipping Sp cross-lamination. Minor concave-upwards surfaces, marked by cP, alternating to undulate-laminated fS layers	shell fragments trace fossils	Storm deposits	
	D_3	Fine sand with parallel-, undulate- to slightly cross-laminations. Sets of laminae separated by thin litho- or bioclastic lags. Symmetrical ripples	marine molluscs trace fossils	Fair-weather deposits	
E	E_1	Medium-to-very-fine sandy deposits, massive or locally showing undulate- to slight cross-lamination. Fossil layers with erosional base surface. Graded lithoclastic lags	shell fragments olygotipic bivalve horizons (*Glicymeris* sp., pectinids, oysters), trace fossils, *Thalassinoides* isp.	moderate-energy storm deposits in the oscillatory wave zone/shoaling wave zone	Lower shoreface
	E_2	Structureless to parallel- or undulate-laminated silty sand, decimetres-thick lamina sets. Partially reworked litho- and bioclastic lags	sparse to layered molluscs *Thalassinoides*-like fossil traces	transition to offshore deposits, distal tempestites	Transition to offshore

Table 1. *Cont.*

Facies Association	Facies	Description	Fossils	Interpretation	Environment
F	F_1	Grey-to-light blue, massive to parallel laminated silty clays	marine micro- and macrofauna vegetal remains	settlement-dominated environment	Prodelta
	F_2	Clay/silty clay deposits, gravel layers	marine micro- and macrofauna vegetal remains	storm- or seismic-induced debris flow deposits, fan-delta bottomset resedimentation.	
G		Massive-to-thinly-laminated gray–blue silty clay, horizontal laminations, fossil horizons	sparse macrofauna mollusc horizons benthic and planktonic foraminifers	settlement-dominated environment below the storm wave-base	Offshore

5.2.2. Gravel Beach-Dominated Coasts (Type 2 Model)

- Unorganized alluvial fan—Facies A_4 (Figure 3b,d, Table 1) characterizes the subaerial part of this coastal model. Deposits are poorly organized, and have been associated with debris flow processes (surging debris flow sensu [10]), in which density is the main acting parameter, with subordinated traction current contribution. Gravel bodies of facies A_4 show poor lateral extension, and they were associated with heavy rainfall-induced landslides on unstable slopes, or parossistic activity of small streams along the paleoshore. Sedimentological features indicate a sudden fall in energy and a short transport. Interpretation: Small and/or isolated alluvial fans.
- Mixed-gravel and sandy beachface—Bodies of gravel and sand, described as alternated and partly eteropic facies C_1 and C_2 (Table 1). Facies C gravel can still be associated with a prograding fan delta front (mouth bar deposits), reworked as gravel beaches deposits. In fact, if the river transport origin is almost clear, originary body geometries are only barely guessable, hidden by the processes associated with wave motion. Gravel (facies C_1) were associated with a relative high-energy beachface, with wave motion redistributing deposits parallel to the paleocoast. Sandy dunes (facies C_2) are interpreted as submerged longshore bars (sensu [1,68,69]) and associated with the shoreface. In fact, a clear distinction between the foreshore and the shoreface is not possible here, and these dunes can be associated with the beachface environment as well (e.g., foreshore and upper shoreface, without a well-defined boundary).
- Shoreface—Where mixed gravel and sand bodies are lacking, deposits can be generically associated with a submerged beach environment, between the average low tide surface and the fair-weather wave base (i.e., the shoreface environment). Nonetheless, in some cases the distinction between upper and lower shoreface can be proposed. The upper shoreface is represented by alternated fair-weather deposits (facies D_3) and storm-induced longshore bar deposits (facies D_2), migrating landwards. Backset laminations, analogous to structures described here as facies D_2, were recently interpreted in terms of supercritical backwash flows at the beachface–shoreface transition [70], still associated with storm deposits and referred to the evolution of a gravelly beach. Although the whole suite of structures was not documented here, probably due to different wave climax, coastal morphologies or outcrop conditions, such a mechanism can be suitable for this case study as well.
- In the lower shoreface deposits (facies E_1), massive-to-undulate slightly cross-laminated sand (fair-weather deposits of the shoaling/oscillatory wave zone) alternated to coarser deposits/fossil layers, interpreted as distal storm deposits.
- Transition to offshore deposits, represented by structureless or subordinately parallel-to undulate-laminated silty sand (facies E_2), with their litho- and bioclastic lags (distal-tempestites), bioturbations, and sparse fossils, are the most common coastal marine

deposits in the area. They were interpreted as transition to offshore deposits, with distal tempestites. Although they could also be associated with the fan-delta coast model, deposits of facies association E have been never documented together with prodelta deposits (facies association F, see below). Thus, they were presumably in lateral eteropy, and facies association E better refers to the gravel beach-dominated coastal model.

5.2.3. Open Marine Environment (Offshore)

Offshore clayey/silty clayey deposits (facies G) appear with similar features throughout the median part of the basin. They are invariantly massive- to thin-laminated, with rare fossil horizons and variable micro- and macrofossil content. This means a homogeneity of distal marine environments, regardless of the coastal type behind it.

In this distal marine environment, although only locally, resedimented gravel of facies F_2 occur (Figure 5d), interposed to clay: they are interpreted as deposits at the bottomset of small, isolated fans and associated with the Type 2 coastal model. At the transition to the open marine, in fact, the influence of nearshore processes was shaded and often indistinguishable.

5.3. Paleocostal Restoration

5.3.1. Comparison with Deltaic and Rocky Coast Facies Distribution and Coastal Models

In the study area, two other coastal models were already proposed (Figure 8), taking into account the braided delta of Città della Pieve, northwards [23,24], and the rocky coast environments, mainly southwards [24,25]. The main differences, as expected, regard the continental and the nearshore sectors. The structured braided-river channels–alluvial plain system, as well as the brackish environment deposits, which characterized the Braided-delta model [23], were replaced by large/coalescent or small/spotted fans in the Type 1 and 2 models, respectively (Figure 8). In its proximal part, the fan-delta front of the Type 1 model still resemble the organization of the braided delta, but it deviated distally; the outer delta large sandy macroforms [23], indeed, were not documented, and replaced by mixedsand and gravel longshore bars (Figure 8). Such fan-delta front organization did not occur in the Type 2 model, where it was replaced by beachface and shoreface deposits.

The rocky coast model [25] was clearly differentiated from the other three models (Figure 8), both in the subaerial portion, where continental/transitional environments were represented by cliffs and cliff thalus, and in the proximal marine environment, in which the sensible lateral variations of facies is replaced by a gravel beachface and a sandy/calcarenitic shoreface. Moreover, in the rocky coast model the gravel beachface showed several facies associations [25], which were not documented in the Type 2 model.

On the other hand, differences tend to progressively reduce seawards, until they disappear in correspondence with the offshore [24]. The Prodelta can be clearly associated only with Braided-delta and Type 1 models (Figure 8), whereas in the Type 2 coastal model it was replaced by a transition-to-offshore environment. In fact, a clear offshore environment cannot be distinguished from the prodelta in the Braided-delta model [23], while it could be indifferently associated with the other three models. Nonetheless, these homogeneous distal clayey to silty clayey deposits still documented minimal variations in both sedimentological features and microfossil assemblages [27,39,67,71–73].

5.3.2. Paleogeographic Distribution of the Paleocoasts

Although they reflect the depositional architecture, Type 1 and 2 coastal models are the ending points of a continuous lateral facies variation which characterized the whole intermediate part of the South Valdichiana basin during the early Pleistocene. The facies analysis suggests an interaction between continental and marine processes inherent in the domains, with the development of a wave-dominated coastal marine environment, in which the fluvial–alluvial origin of deposits was still more or less recognizable. The main distinguishing factor was represented by the occurrence of structured fan-delta

systems or of spotted river mouths, both associated with seasonal streams or parossistic events rather than with a persistent fluvial environment behind. These streams mainly supplied coarse-grained deposits, reworked by waves into partly redistributed mouth bar deposits or gravel beach deposits [24] (Figure 5b). Facies associated with the Type 1 model were documented in some restricted areas (Figure 1c): in these sectors, inherited coastal morphologies probably led to the development of a narrow, gently inclined band between the reliefs and the coast line, occupied by large or coalescing fans (bajada [65,66]) and their fan-deltas. The presence of such a band, indeed, caused the slope break and the energy fall did not occur directly into the sea; conditions necessary to define a fan-delta [65,66,74].

5.3.3. Fossil Distribution and Stratigraphic Constraints

Both Type 1 and 2 coastal models were stratigraphically constrained to the early Pleistocene (Cycle II—Valdichiana Cycle in Figure 2, [24]), although they could still be applied to the "Pliocene" Cycle as well. In fact, former studies documented middle-to-late Villafranchian freshwater to continental fossil assemblages [34,75], and the hypothesis of an older coastal evolution for the area was already suggested [23,24], although therewas a lack of continuous biostratigraphic data.

Beyond stratigraphy, the fossil record manifests a substantial homogeneity throughout the study area, and across the two coastal models. It was discussed [26,27] how the distribution of selected benthic foraminifers, molluscs, corals (*Cladocora*) and lunulite bryozoans mainly depended onthe bathymetry and the lithology/grain size of the sea floor, rather than from the coastal type at the rear. Other important factors were the water temperature [26,76] and chemistry [39], the local availability of nutrients [69–71], and the relative sea-level rise/fall [23–26].

Lack of fossil record, common presence of vegetal remains, as well as mixed assemblages of freshwater and altered salinity-tolerant species, characterized the continental/transitional environment deposits in the area [23,24]. Following only this criterion, alluvial fan/fan delta deposits are not easily distinguishable from deposits associated with braided delta [23], particularly on small outcrops: in these cases, only a wider paleoenvironmental and depositional architecture analysis led to reliable reconstructions [24].

Proximal marine environments were dominated by infralittoral species, with an increasing seawards presence of circalittoral to upper bathial forms [27]. Nonetheless, PE assemblages (Heterogeneous Populations sensu [77]) were commonly (although locally) reported through the whole area, in deposits referred to the infralittoral–upper circalittoral interval, and they are commonly associated with the distribution of lunulite bryozoans [27]. As expected, nearshore deposits (i.e., the ones associated with beachface/shoreface or middle fan-delta front) are commonly characterized by vegetal remains, shell debris, and dominated by *Amphistegina* spp., *Elphidium* spp., and *Ammonia* spp. benthic foraminifers [27]. In the same environments, *Persististrombus coronatus*, oysters (*Ostrea lamellosa*, *O. edulis*), pectinids (*Chlamys* spp., *Pecten jacobaeus*, *Flabellipecten flabelliformis*), and *Chamalea gallina* commonly occur among the malacofauna. Reacher and various assemblages of both macro- and microfauna characterized the lower shoreface/transition to offshore and outer delta/prodelta deposits, still in the infralittoral–upper circalittoral interval [27,76,78], as well as the offshore deposits (lower circalittoral–upper bathial), although with prevalence of different species [27,67].

Fossil data support the proposed coastal models: Type 1 and Type 2 paleocoasts (as well as braided-river delta and rocky paleocoasts) laterally coexisted, gradually shading seawards into a more homogeneous distal marine environment. The main differences were led by inherited morphologies and processes active on the emerged areas (physical factors), rather than by paleoecological/paleoenvironmental conditions (biological factors) or stratigraphy (geological time) [24].

6. Conclusions

Through the Pliocene (?)—early Pleistocene shallow marine deposits, cropping out in the southern sector of the Valdichiana Basin (particularly in its intermediate part), facies associations allow us to reconstruct the evolution of a wave-dominated, river-fed coast [24].

Spotted to coalescent alluvial fan/fan-delta deposits, more or less reworked by waves and redistributed as gravel and sandy beaches, characterized the nearshore; theirsmooth seaward morphology, on a coast-transverse profile, resembled the shelf-type fan-delta models [8].

Two coastal models are proposed here, indicated as Type 1 (Fan-delta-dominated) and Type 2 (Gravel beach-dominated), respectively, laterally shading each one in with other, and both tending to a substantial homogeneity seawards. The main differences in the distribution of facies, indeed, both between the two models and with the braided delta and the rocky coast models (still characterizing discrete sectors of the study area [23–25]), concentrate in the nearshore (Figure 8).

According to biostratigraphic and paleoecological data, the four models coexisted at least during part of the early Pleistocene, presumably as a consequence of inherited geomorphologic features and the evolution of neighbouring alluvial environments.

This Miocene to recent evolution of both northern and eastern emerged areas, although partially defined [23,24,44,45,79], is still not fully assessed. Open research lines are oriented in such a direction.

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